

# Claims

- [c1] 1. A method for real-time determination of exhaust gas flow through an exhaust pipe of a vehicle, the method comprising:  
measuring a pressure difference upstream and downstream of a screen;  
measuring exhaust gas temperature; and  
determining the exhaust gas flow based on the pressure difference and the temperature.
- [c2] 2. The method of claim 1 wherein the step of determining the exhaust gas flow comprises determining the exhaust gas flow based on a square root of the quotient of the pressure difference and the temperature.
- [c3] 3. The method of claim 2 wherein the step of determining the exhaust gas flow further comprises: determining a constant based on known flows, known temperatures, and a measured pressure difference; and multiplying the constant by the square root.
- [c4] 4. The method of claim 1 wherein the step of determining the exhaust gas flow comprises determining the exhaust gas flow according to:

$\text{Flow} = K * (\text{pressure difference})^x * (\text{temperature})^y$  where "K" represents a constant.

- [c5] 5. The method of claim 4 further comprising:  
measuring the pressure difference for a plurality of known flows and a constant temperature; and  
determining slope of the logarithm of the known flows as a function of the logarithm of the pressure differences to determine a value for the exponent "x".
- [c6] 6. The method of claim 4 further comprising:  
measuring the pressure difference for a plurality of known temperatures and a constant flow; and  
determining slope of the logarithm of the quotient of the flow and the pressure difference as a function of the logarithm of the temperature for each temperature; and  
averaging the slopes for each temperature to determine a value for the exponent "y".
- [c7] 7. The method of claim 4 wherein a value for "K" is empirically determined.
- [c8] 8. The method of claim 1 wherein the step of determining the exhaust gas flow comprises determining the exhaust gas flow according to:  
 $\text{differential pressure} = A * \text{flow} + B * \text{flow}^2$   
where "A" and "B" are empirically determined constants.

- [c9] 9. The method of claim 8 wherein "A" and "B" are determined during calibration by measuring differential pressures across the screen during a low flow condition and a high flow condition, respectively, at a reference exhaust gas temperature and ambient pressure.
- [c10] 10. The method of claim 8 wherein the step of determining the exhaust gas flow further comprises adjusting the real-time measured pressure difference based on the measured exhaust gas temperature, the reference exhaust gas temperature, measured ambient pressure, and the reference ambient pressure.
- [c11] 11. The method of claim 10 wherein the real-time measured pressure difference is adjusted by multiplying by a factor "K", where:  $K = (T_{REF} / T_{actual})^{-2Y} (P_{Ambient} / P_{REF})$  and "Y" is determined based on a relationship of differential pressure as a function of temperature for the low flow and high flow conditions.
- [c12] 12. The method of claim 1 wherein the screen covers substantially the entire area of the exhaust pipe.
- [c13] 13. The method of claim 1 wherein the screen mesh is selected to generate a measurable pressure difference while minimizing back pressure and formation of condensation on the screen.

- [c14] 14. The method of claim 1 wherein the screen includes about six strands per inch arranged in a generally rectangular array that extends across the exhaust pipe.
- [c15] 15. A portable system for determining exhaust gas flow of a vehicle, the system comprising:  
a tube adapted for placement on an exhaust pipe of the vehicle, the tube including a flow restricting element extending across a cross-sectional area of the tube, a first port disposed upstream of the flow restricting element for measuring a first pressure, and a second port disposed downstream of the flow restricting element for measuring a second pressure; and  
a device in communication with the tube for determining the exhaust gas flow based on a difference between the first and second pressures.
- [c16] 16. The system of claim 15 wherein the tube further comprises a third port for measuring temperature of exhaust gas flowing through the tube.
- [c17] 17. The system of claim 16 further comprising a thermocouple extending through the third port and in communication with the device to measure temperature of the exhaust gas flowing through the tube.
- [c18] 18. The system of claim 16 wherein the device deter-

mines the exhaust gas flow based on a difference between the first and second pressures and the temperature of the exhaust gas.

- [c19] 19. The system of claim 15 wherein the device includes at least one differential pressure transducer to generate a signal based on the difference between the first and second pressures.
- [c20] 20. The system of claim 15 wherein the flow restricting element comprises a screen.
- [c21] 21. The system of claim 20 wherein the screen comprises a plurality of strands arranged in a generally square array with less than ten strands per inch.
- [c22] 22. The system of claim 20 wherein the screen is made of stainless steel.
- [c23] 23. The system of claim 15 wherein the flow restricting element comprises a disk having regularly spaced openings.
- [c24] 24. The system of claim 23 wherein the openings comprise between 60% and 65% of the cross-sectional area of the disk.
- [c25] 25. The system of claim 15 wherein the device includes a microprocessor to determine the exhaust gas flow.

- [c26] 26. The system of claim 15 wherein the tube is straight to reduce added back pressure.
- [c27] 27. The system of claim 15 wherein the flow restricting element includes sufficient spaces to limit any increase in back pressure to less than six percent.
- [c28] 28. The system of claim 15 wherein the device comprises:  
a first differential pressure transducer generating a first signal based on the difference between the first and second pressures corresponding to a first range of exhaust flows; and  
a second differential pressure transducer generating a second signal based on the difference between the first and second pressures corresponding to a second range of exhaust flows.
- [c29] 29. The system of claim 15 further comprising:  
a condensation trap positioned upstream relative to the flow restricting element.
- [c30] 30. The system of claim 29 wherein the condensation trap comprises:  
a conical screen having an apex pointing upstream; and  
a baffle disposed downstream of the conical stream.

- [c31] 31. The system of claim 15 wherein the tube further comprises a fourth port for extracting samples of exhaust gas passing through the tube.
- [c32] 32. A portable exhaust gas flow sensor for real-time on-board measurement of exhaust gas flow from a vehicle, the sensor comprising:  
a straight tube for connecting to an exhaust pipe of the vehicle, the tube including an interior screen to generate a pressure drop as exhaust gas flows across the screen, an upstream port for measuring pressure upstream of the screen, a downstream port for measuring pressure downstream of the screen, and a thermocouple port for measuring exhaust gas temperature;  
a differential pressure transducer in communication with the upstream and downstream ports for generating a signal based on a pressure difference between the upstream and downstream ports;  
a thermocouple in communication with the thermocouple port for generating a signal based on temperature of exhaust gas flowing through the straight tube; and  
a processor for receiving the signals from the differential pressure transducer and the thermocouple and determining exhaust gas flow based on the received signals.
- [c33] 33. The sensor of claim 32 further comprising:  
a second differential pressure transducer in communica-

tion with the upstream and downstream ports for generating a second differential pressure signal based on the pressure difference between the upstream and downstream ports, wherein the first differential pressure signal corresponds to a first range of exhaust gas flows and the second differential pressure signal corresponds to a second range of exhaust gas flows.

[c34] 34. The sensor of claim 33 wherein the processor selects one of the first and second differential pressure signals to use in determining the exhaust gas flow.

[c35] 35. The sensor of claim 32 wherein the processor determines exhaust gas flow according to:  
exhaust gas flow =  $K\Delta P^x T^y$   
where  $\Delta P$  represents the differential pressure,  $T$  represents the temperature of the exhaust gas, and  $K$ ,  $x$ , and  $y$  are empirically determined.